Appendix B:
HVAC Systems and Indoor Air Quality

This appendix provides information about specific HVAC system designs and components in relation to indoor air quality. It also serves as introductory material for building owners and managers who may be unfamiliar with the terminology and concepts associated with HVAC (heating, ventilating, and air conditioning) system design. Further detailed information can be found in ASHRAE manuals and guides and in some of the guidance developed by other trade and professional associations. (See *Guidelines of Care Developed by Trade Associations* in Section 5.) Additional information can be obtained using *Appendix G* or through discussion with your facility engineer.

BACKGROUND

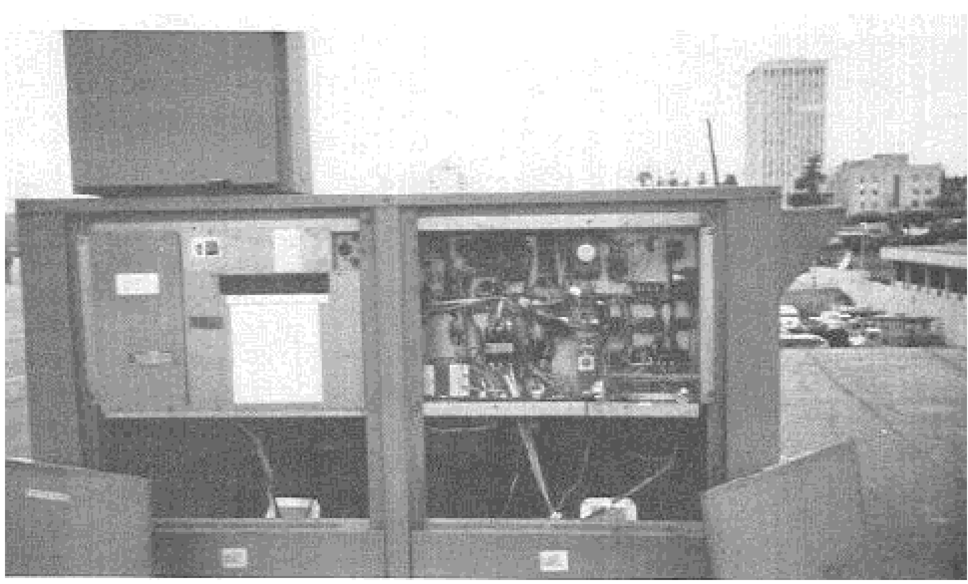
All occupied buildings require a supply of outdoor air. Depending on outdoor conditions, the air may need to be heated or cooled before it is distributed into the occupied space. As outdoor air is drawn into the building, indoor air is exhausted or allowed to escape (passive relief), thus removing air contaminants.

The term “HVAC system” is used to refer to the equipment that can provide heating, cooling, filtered outdoor air, and humidity control to maintain comfort conditions in a building. Not all HVAC systems are designed to accomplish all of these functions. Some buildings rely on only natural ventilation. Others lack mechanical cooling equipment (AC), and many function with little or no humidity control. The features of the HVAC system in a given building will depend on several variables, including:

- age of the design
- climate
- building codes in effect at the time of the design
- budget that was available for the project
- planned use of the building
- owners’ and designers’ individual preferences
- subsequent modifications

HVAC systems range in complexity from stand-alone units that serve individual rooms to large, centrally controlled systems serving multiple zones in a building. In large modern office buildings with heat gains from lighting, people, and equipment, interior spaces often require year-round cooling. Rooms at the perimeter of the same building (i.e., rooms with exterior walls, floors, or roof surfaces) may need to be heated and/or cooled as hourly or daily outdoor weather conditions change. In buildings over one story in height, perimeter areas at the lower levels also tend to experience the greatest uncontrolled air infiltration.

Working with the electrical components of an HVAC system involves the risk of electrocution and fire. A knowledgeable member of the building staff should oversee the inspection of the HVAC controls.



Some buildings use only natural ventilation or exhaust fans to remove odors and contaminants. In these buildings, thermal discomfort and unacceptable indoor air quality are particularly likely when occupants keep the windows closed because of extreme hot or cold temperatures. Problems related to underventilation are also likely when infiltration forces are weakest (i.e., during the "swing seasons" and summer months).

Modern public and commercial buildings generally use mechanical ventilation systems to introduce outdoor air during the occupied mode. Thermal comfort is commonly maintained by mechanically distributing conditioned (heated or cooled) air throughout the building. In some designs, air systems are supplemented by piping systems that carry steam or water to the building perimeter zones. As this document is concerned with HVAC systems in relation to indoor air quality, the remainder of this discussion will focus on systems that distribute conditioned air to maintain occupant comfort.

Roles of the HVAC System Operator and Facility Manager

The system operator(s) and facility manager(s) (or IAQ manager) are among the most significant factors in determining whether IAQ problems will occur in a properly designed, constructed, and commissioned HVAC system. HVAC systems require preventive maintenance and prompt repairs if they are to operate correctly and provide comfortable conditions. The operator(s) must have an adequate understanding of the overall system design and its limitations. The HVAC system capacity and distribution characteristics should be evaluated before renovations to the building, changes in its occupancy, or changes in the use of an area.

System operators must be able to respond appropriately to occupant complaints. For example, if an occupant complains that it is too cold or too hot and the observed (measured) conditions are outside of the ASHRAE comfort zone, then the HVAC system needs to be evaluated. Sometimes the problem can be relieved by fine tuning or repairing the HVAC system, but in some cases the system cannot perform as expected, and a long-term solution must be investigated.

TYPES OF HVAC SYSTEMS

Single Zone

A single air handling unit can only serve more than one building area if the areas served have similar heating, cooling, and ventilation requirements, or if the control system compensates for differences in heating, cooling, and ventilation needs among the spaces served. Areas regulated by a common control (e.g., a single thermostat) are referred to as zones. Thermal comfort problems can result if the design does not adequately account for differences in heating and cooling loads between rooms that are in the same zone. This can easily occur if:

- The cooling load in some area(s) within a zone changes due to an increased occupant population, increased lighting, or the introduction of new heat-producing equipment (e.g., computers, copiers).
- Areas within a zone have different solar exposures. This can produce radiant heat gains and losses that, in turn, create unevenly distributed heating or cooling needs (e.g., as the sun angle changes daily and seasonally).

Multiple Zone

Multiple zone systems can provide each zone with air at a different temperature by heating or cooling the airstream in each zone. Alternative design strategies involve delivering air at a constant temperature while varying the volume of airflow, or modulating room temperature with a supplementary system (e.g., perimeter hot water piping).

Constant Volume

Constant volume systems, as their name suggests, generally deliver a constant airflow to each space. Changes in space temperatures are made by heating or cooling the air or switching the air handling unit on and off, not by modulating the volume of air supplied. These systems often operate with a fixed minimum percentage of outdoor air or with an "air economizer" feature (described in the *Outdoor Air Control* discussion that follows).

Variable Air Volume

Variable air volume systems maintain thermal comfort by varying the amount of heated or cooled air delivered to each space, rather than by changing the air temperature. (However, many VAV systems also have provisions for resetting the temperature of the delivery air on a seasonal basis, depending on the severity of the weather). Overcooling or overheating can occur within a given zone if the system is not adjusted to respond to the load. Underventilation frequently occurs if the system is not arranged to introduce at least a minimum quantity (as opposed to percentage) of outdoor air as the VAV system throttles back from full airflow, or if the system supply air temperature is set too low for the loads present in the zone.

BASIC COMPONENTS OF AN HVAC SYSTEM

The basic components of an HVAC system that delivers conditioned air to maintain thermal comfort and indoor air quality are:

- outdoor air intake
- mixed-air plenum and outdoor air control
- air filter
- heating and cooling coils
- humidification and/or de-humidification equipment

TESTING AND BALANCING

Modern HVAC systems typically use sophisticated, automatic controls to supply the proper amounts of air for heating, cooling, and ventilation in commercial buildings. Problems during installation, operation, maintenance, and servicing the HVAC system could prevent it from operating as designed. Each system should be tested to ensure its initial and continued performance. In addition to providing acceptable thermal conditions and ventilation air, a properly adjusted and balanced system can also reduce operating costs and increase equipment life.

Testing and balancing involves the testing, adjusting, and balancing of HVAC system components so that the entire system provides airflows that are in accordance with the design specifications. Typical components and system parameters tested include:

- all supply, return, exhaust, and outdoor airflow rates
- control settings and operation
- air temperatures
- fan speeds and power consumption
- filter or collector resistance

The typical test and balance agency or contractor coordinates with the control contractor to accomplish three goals: verify and ensure the most effective system operation within the design specifications, identify and correct any problems, and ensure the safety of the system.

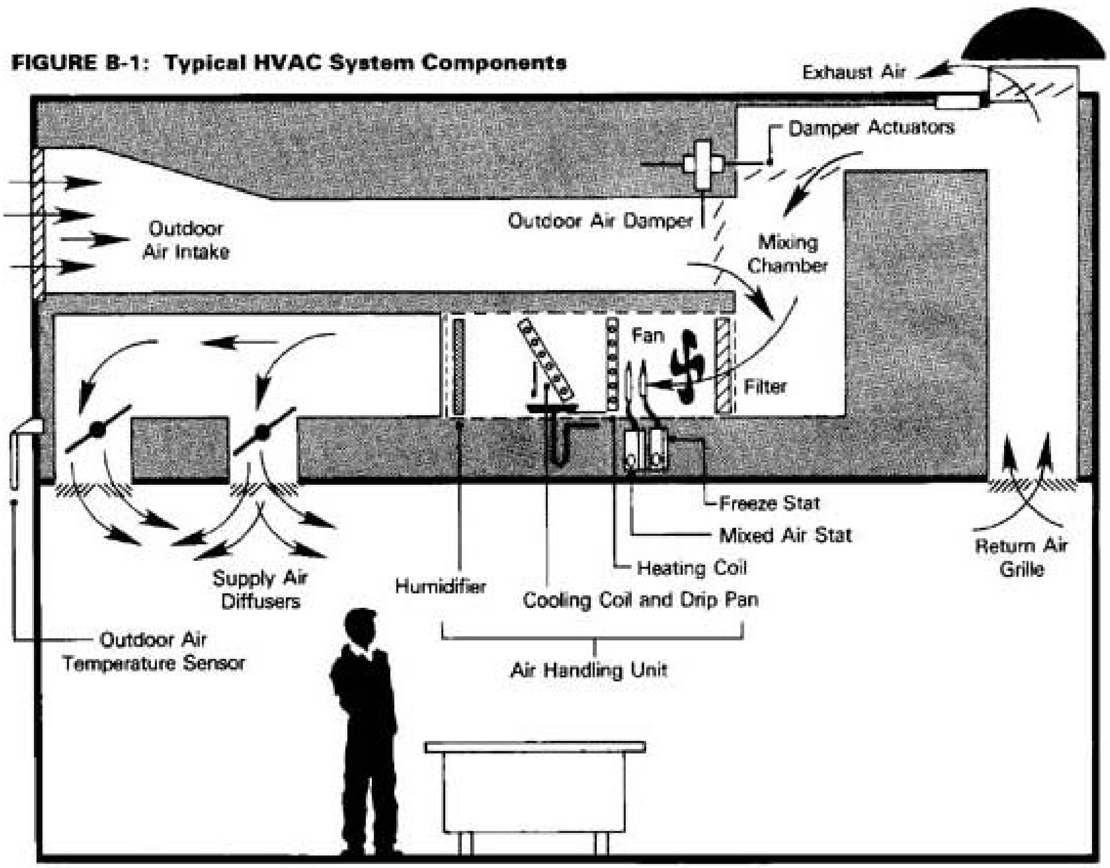
A test and balance report should provide a complete record of the design, preliminary measurements, and final test data. The report should include any discrepancies between the test data and the design specifications, along with reasons for those discrepancies. To facilitate future performance checks and adjustments, appropriate records should be kept on all damper positions, equipment capacities, control types and locations, control settings and operating logic, airflow rates, static pressures, fan speeds, and horsepowers.

Testing and balancing of existing building systems should be performed whenever there is reason to believe the system is not functioning as designed or when current records do not accurately reflect the actual operation of the system. The Associated Air Balance Council recommends the following guidelines in determining whether testing and balancing is required:

- When space has been renovated or changed to provide for new occupancy.
- When HVAC equipment has been replaced or modified.
- When control settings have been readjusted by maintenance or other personnel.
- After the air conveyance system has been cleaned.
- When accurate records are required to conduct an IAQ investigation.
- When the building owner is unable to obtain design documents or appropriate air exchange rates for compliance with IAQ standards or guidelines.

Because of the diversity of system types and the interrelationship of system components, effective balancing requires a skilled technician with the proper experience and instruments. Due to the nature of the work, which involves the detection and remediation of problems, it is recommended that an independent test and balance contractor be used and that this contractor report directly to the building owner, facility manager, or IAQ manager.

FIGURE B-1: Typical HVAC System Components



Courtesy Terry Brennan
Camroden Associates
Oriskny, N.Y.

- supply fan
- ducts
- terminal device
- return air system
- exhaust or relief fans and air outlet
- self-contained heating or cooling unit
- control
- boiler
- cooling tower
- water chiller

The following discussion of these components (each of which may occur more than once in any total HVAC system) emphasizes features that affect indoor air quality. It may be helpful to refer to this section when using the **HVAC Checklists**.

The illustration above shows the general relationship between many of these components; however, many variations are possible.

Outdoor Air Intake

Building codes require the introduction of outdoor air for ventilation in most buildings. Most non-residential air handlers are designed with an outdoor air intake on the return side of the ductwork. Outdoor air introduced through the air handler can be filtered and conditioned (heated or cooled) before distribution. Other designs may introduce outdoor air through air-to-air heat exchangers and operable windows.

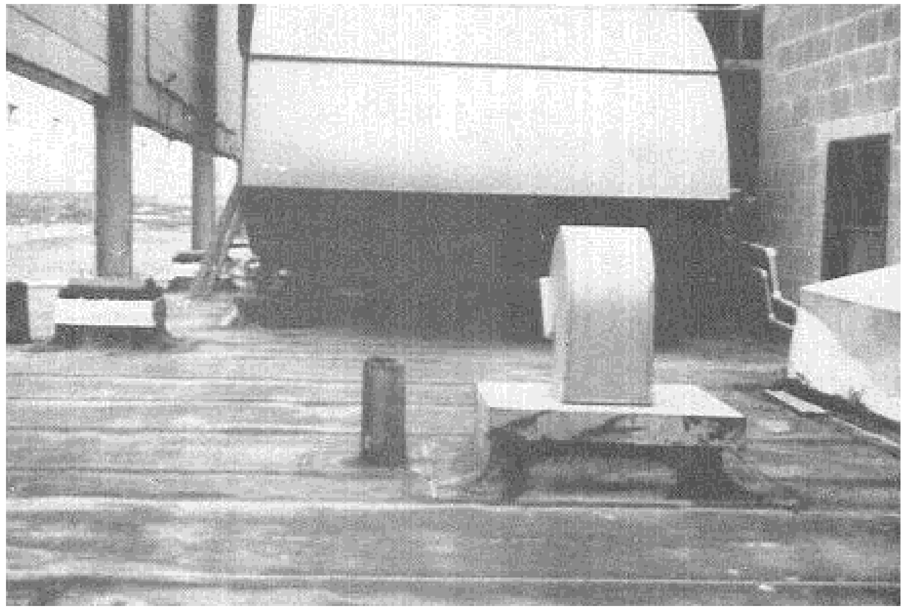
Indoor air quality problems can be produced when contaminants enter a building with the outdoor air. Rooftop or wall-mounted air intakes are sometimes located adjacent to or downwind of building exhaust outlets or other contaminant sources. Problems can also result if debris (e.g., bird droppings) accumulates at the intake, obstructing airflow and potentially introducing microbiological contaminants.

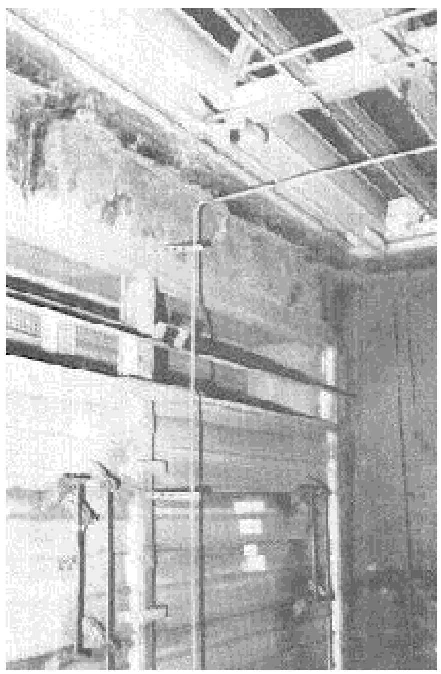
If more air is exhausted than is introduced through the outdoor air intake, then outdoor air will enter the building at any leakage sites in the shell. Indoor air quality problems can occur if the leakage site is a door to a loading dock, parking garage, or some other area associated with pollutants.

Mixed-Air Plenum and Outdoor Air Controls

Outdoor air is mixed with return air (air that has already circulated through the HVAC system) in the mixed-air plenum of an air handling unit. Indoor air quality problems frequently result if the outdoor air damper is not operating properly (e.g., if the system is not designed or adjusted to allow the introduction of sufficient outdoor air for the current use of the building. The amount of outdoor air introduced in the occupied mode should be sufficient to meet needs for ventilation and exhaust make-up. It may be fixed at a constant volume or may vary with the outdoor temperature.

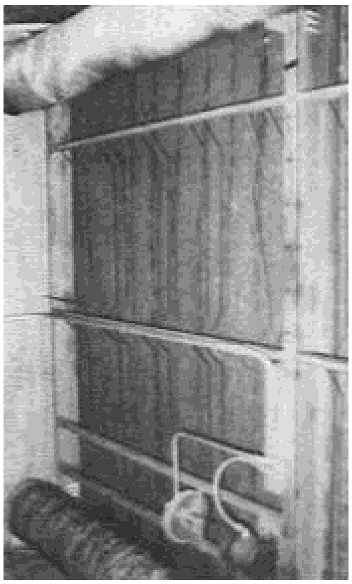
When dampers that regulate the flow of outdoor air are arranged to modulate, they are usually designed to bring in a minimum amount of outdoor air (in the occupied mode) under extreme outdoor temperature conditions and to open as outdoor temperatures approach the desired indoor temperature. Systems that use outdoor air for cooling are called "air economizer cooling" systems. Air economizer systems have a mixed air





Above: *The air intake in the background is located too close to the sanitary vents (the straight pipes to the left and in the center foreground) and the bathroom exhaust vent (next to the sanitary vent on the right side).* ***Below:*** *The return air dampers in this mixed-air plenum are open (top), but the outdoor air damper (left) is almost completely closed. Complaints in the building indicate that under-ventilation is a problem.*

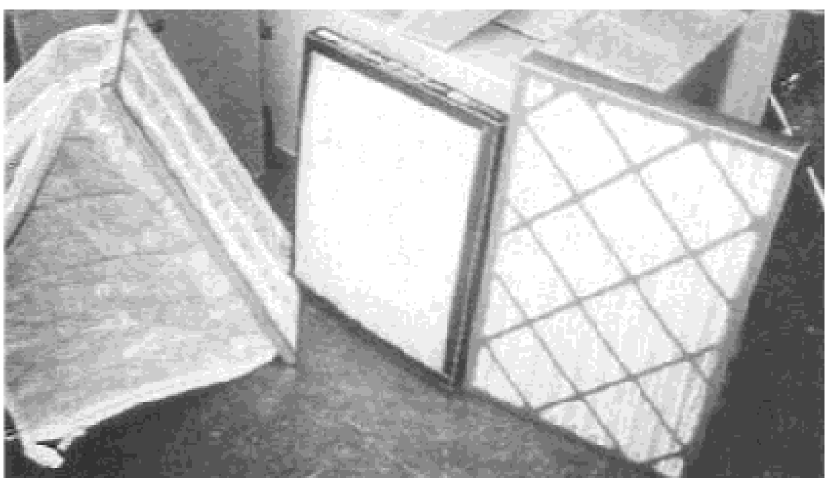
temperature controller and thermostat that are used to blend return air (typically at 74°F) with outdoor air to reach a mixed air temperature of 55° to 65°F. (Mixed air temperature settings above 65°F may lead to the introduction of insufficient quantities of outdoor air for office space use.) The mixed air is then further heated or cooled for delivery to the occupied spaces.



Air economizer systems have a sensible or enthalpy control that signals the outdoor air damper to go to the minimum position when it is too warm or humid outdoors. Note that economizer cycles which do not provide dehumidification may produce discomfort even when the indoor temperature is the same as the thermostat setting.

If outdoor air make-up and exhaust are balanced, and the zones served by each air handler are separated and well defined, it is possible to estimate the minimum flow of outdoor air to each space and compare it to ventilation standards such as ASHRAE 62-1989. Techniques used for this evaluation include the direct measurement of the outdoor air at the intake and the calculation of the percentage of outdoor air by a temperature or CO_2 balance. Carbon dioxide measured in an occupied space is also an indicator of ventilation adequacy. Some investigators use tracer gases to assess ventilation quantities and airflow patterns. There are specific methods for each of these assessments. See *Appendix A* for more information.

Many HVAC designs protect the coils by closing the outdoor air damper if the airstream temperature falls below the setpoint of a freezestat. Inadequate ventilation can occur if a freezestat trips and is not reset, or if the freezestat is set to trip at an excessively high temperature. Stratification of the cold outdoor air and warmer return air in the mixing plenums is a common situation, causing nuisance tripping of the freezestat. Unfortunately, the remedy often employed to prevent this problem is to close the outdoor air damper. Obviously, solving the problem in this way can quickly lead to inadequate outdoor air in occupied parts of the building.



Proper air filtration can play an impor-tant role in protecting the rest of the HVAC system and in maintaining good indoor air quality in occupied spaces. Air filters should be selected and main-tained to provide maximum filtration, while not overtaxing the supply fan capability or leading to "blow out" situa-tions with no air filtration. Shown above are roll filter (top) and bag, panel, and pleated filters (below).

Air Filters

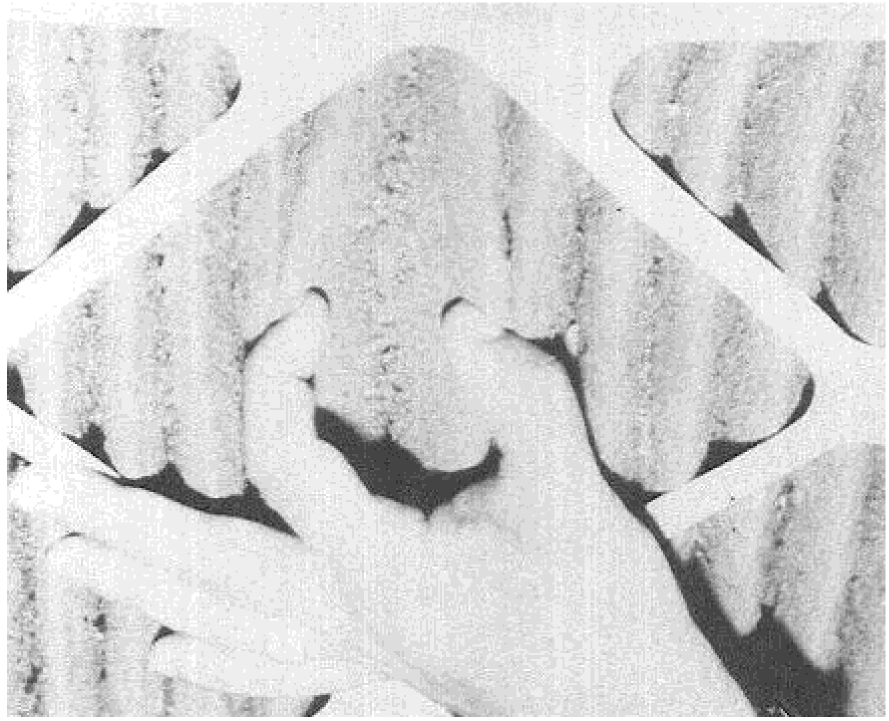
Filters are primarily used to remove particles from the air. The type and design of filter determine the efficiency at removing particles of a given size and the amount of energy needed to pull or push air through the filter. Filters are rated by different standards and test methods such as dust spot and arrestance which measure different aspects of performance. See the discussion of ASHRAE Standard 52-76 on page 138 of this appendix.

Low efficiency filters (ASHRAE Dust Spot rating of 10% to 20% or less) are often used to keep lint and dust from clogging the heating and cooling coils of a system. In order to maintain clean air in occupied spaces, filters must also remove bacteria, pollens, insects, soot, dust, and dirt with an efficiency suited to the use of the building. Medium efficiency filters (ASHRAE Dust Spot rating of 30% to

60%) can provide much better filtration than low efficiency filters. To maintain the proper airflow and minimize the amount of additional energy required to move air through these higher efficiency filters, pleated-type extended surface filters are recommended. In buildings that are designed to be exceptionally clean, the designers may specify the equipment to utilize both a medium efficiency pre-filter and a high efficiency extended surface filter (ASHRAE Dust Spot rating of 85% to 95%). Some manufacturers recommend high efficiency extended surface filters (ASHRAE Dust Spot rating of 85%) without pre-filters as the most cost effective approach to minimizing energy consumption and maximizing air quality in modern HVAC VAV systems that serve office environments.

Air filters, whatever their design or efficiency rating, require regular maintenance (cleaning for some and replacement for most). As a filter loads up with particles, it becomes more efficient at particle removal but increases the pressure drop through the system, therefore reducing airflow. Filter manufacturers can provide information on the pressure drop through their products under different conditions. Low efficiency filters, if loaded to excess, will become deformed and even "blow out" of their filter rack. When filters blow out, bypassing of unfiltered air can lead to clogged coils and dirty ducts. Filtration efficiency can be seriously reduced if the filter cells are not properly sealed to prevent air from bypassing.

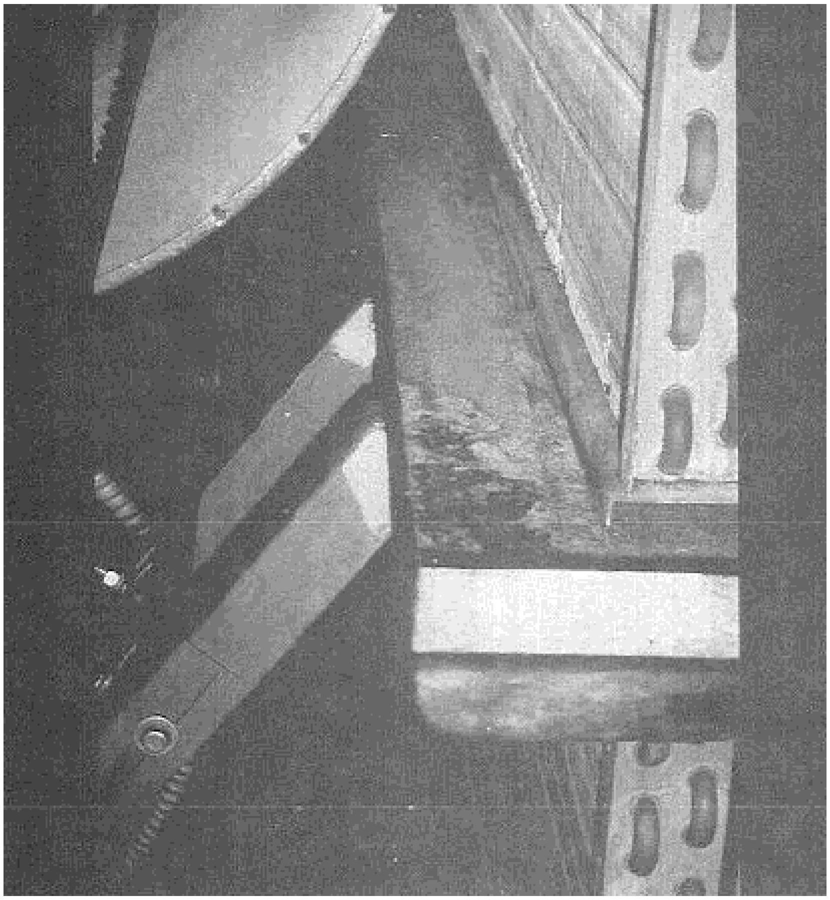
Filters should be selected for their ability to protect both the HVAC system components and general indoor air quality. In many buildings, the best choice is a medium efficiency, pleated filter because these filters have a higher removal efficiency than low efficiency filters, yet they will last without clogging for longer than high efficiency filters.



Pleated medium efficiency filters are often preferred over low efficiency filters because they offer added protection to both the HVAC equipment and to indoor air quality, yet they do not clog as easily as high efficiency filters. Medium efficiency filters do need routine maintenance, however, which the filter in this photo did not receive.

Choice of an appropriate filter and proper maintenance are important to keeping the ductwork clean. If dirt accumulates in ductwork and if the relative humidity reaches the dewpoint (so that condensation occurs), then the nutrients and moisture may support the growth of microbiologicals. Attention to air filters is particularly important in HVAC systems with acoustical duct liner, which is frequently used in air handler fan housings and supply ducts to reduce sound transmission and provide thermal insulation. Areas of duct lining that have become contaminated with microbiological growth must be replaced. (See later discussion of ducts and duct cleaning .) Sound reduction can also be accomplished with the use of special duct-mounted devices such as attenuators or with active electronic noise control.

Air handlers that are located in difficult-to-access places (e.g., in places which require ladders for access, have inconvenient access doors to unbolt, or are located on roofs with no roof hatch access) will be



Without proper installation and maintenance, rust and corrosion may accumulate in condensate pans under heating and cooling coils. The rust in the pan indi-cates that it was installed without a pitch or was pitched in the wrong direction, so that water did not drain out properly.

more likely to suffer from poor air filter maintenance and overall poor maintenance. Quick release and hinged access doors for maintenance are more desirable than bolted access panels.

Filters are available to remove gases and volatile organic contaminants from ventilation air; however, these systems are not generally used in normal occupancy buildings. In specially designed HVAC systems, permanganate oxidizers and activated charcoal may be used for gaseous removal filters. Some manufacturers offer “partial bypass” carbon filters and carbon impregnated filters to reduce volatile organics in the ventilation air of office environments. Gaseous filters must be regularly maintained (replaced or regenerated) in order for the system to continue to operate effectively.

Heating and Cooling Coils

Heating and cooling coils are placed in the airstream to regulate the temperature of the air delivered to the space. Malfunctions of the coil controls can result in thermal discomfort. Condensation on under-insulated pipes and leakage in piped systems will often create moist conditions conducive to the growth of molds, fungus, and bacteria.

During the cooling mode (air conditioning), the cooling coil provides dehumidification as water condenses from the airstream. Dehumidification can only take place if the chilled fluid is maintained at a cold enough temperature (generally below 45°F for water). Condensate collects in the drain pan under the cooling coil and exits via a deep seal trap. Standing water will accumulate if the drain pan system has not been designed to drain completely under all operating conditions (sloped toward the drain and properly trapped). Under these conditions, molds and bacteria will proliferate unless the pan is cleaned frequently.

It is important to verify that condensate lines have been properly trapped and are charged with liquid. An improperly trapped line can be a source of contamination, depending on where the line terminates. A properly installed trap could also be a source, if the water in the trap evaporates and allows air to flow through the trap into the conditioned air.

During the heating mode, problems can occur if the hot water temperature in the heating coil has been set too low in an attempt to reduce energy consumption. If enough outdoor air to provide sufficient ventilation is brought in, that air may not be heated sufficiently to maintain thermal comfort or, in order to adequately condition the outdoor air, the amount of outdoor air may be reduced so that there is insufficient outdoor air to meet ventilation needs.

Humidification and Dehumidification Equipment

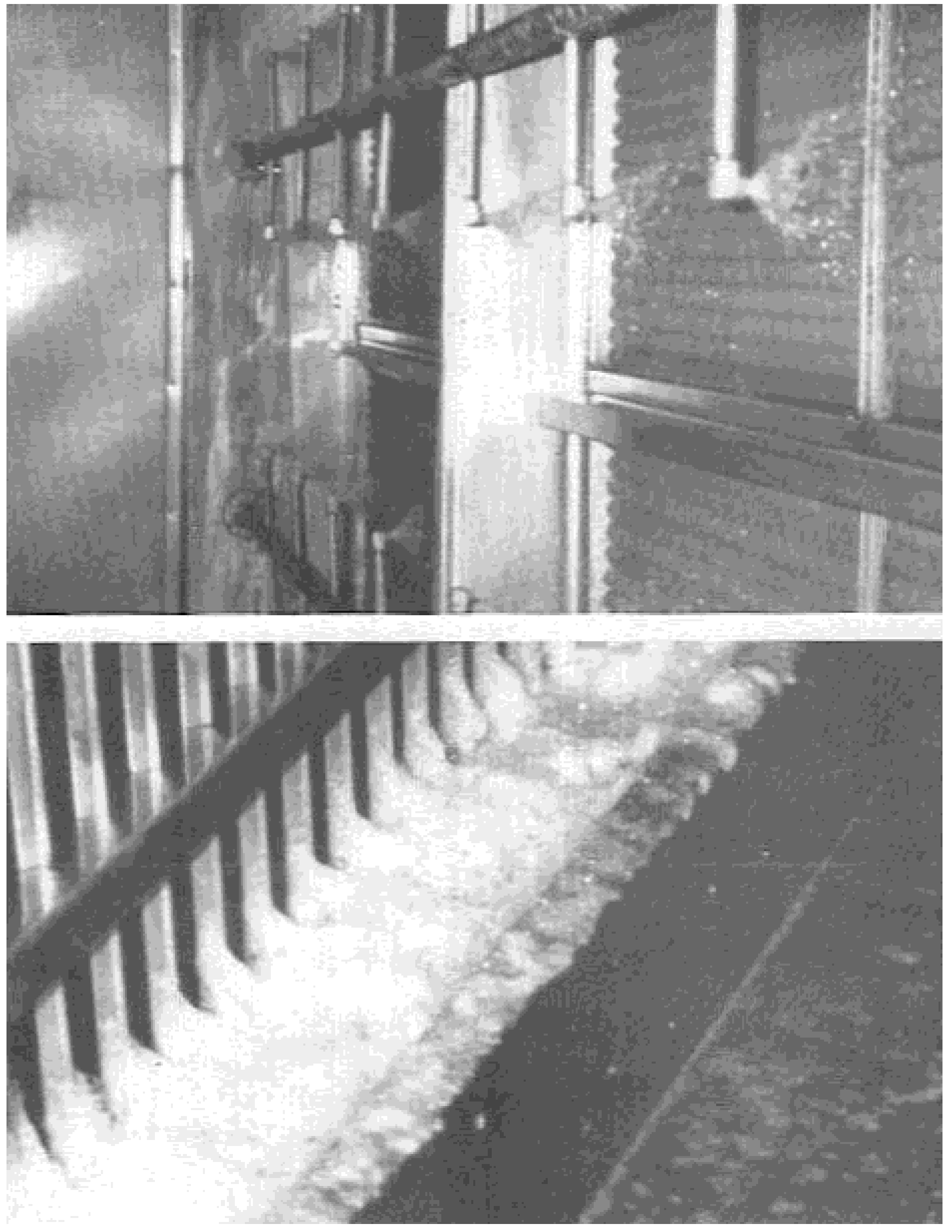
In some buildings (or zones within buildings), there are special needs that warrant the strict control of humidity (e.g., operating rooms, computer rooms). This control is most often accomplished by adding humidification or dehumidification equipment and controls. In office facilities, it is generally preferable to keep relative humidities above 20% or 30% during the heating season and below 60% during the cooling season. ASHRAE Standard 55-1981 provides guidance on acceptable temperature and humidity conditions. (See also the discussion of humidity levels in *Section 6*.)

The use of a properly designed and operated air conditioning system will generally keep relative humidities below 60% RH during the cooling season, in office facilities with normal densities and loads. (See the previous discussion of the cooling coil.)

Office buildings in cool climates that have high interior heat gains, thermally efficient envelopes (e.g., insulation), and economizer cooling may require humidification to maintain relative humidity within the comfort zone. When humidification is needed, it must be added in a manner that prevents the growth of microbiologicals within the ductwork and air handlers.

Steam humidifiers should utilize clean steam, rather than treated boiler water, so that occupants will not be exposed to chemicals. Systems using media other than clean steam must be rigorously maintained in accordance with the manufacturer's recommended procedures to reduce the likelihood of microbiological growth.

Mold growth problems are more likely if the humidistat setpoint located in the occupied space is above 45%. The high limit humidistat, typically located in the ductwork downstream of the point at



Above: Occupants of this building complained of an inter-mittant fish tank odor. An investigation showed that this water spray humidifi-cation system is regularly maintained. The coils are washed roughly every two weeks using fresh tap water, eliminating the need for any use of algacides. Below: Further investigation identified the fact that the maintenance practice was causing the odor problem. This picture of the downstream side of the coils was taken one day after the washing. A high pressure stream of water caused algae in the water to foam and float for several days, coinciding with the occupant complaints.

DUCT LEAKAGE

Leakage of air from ducts can cause or exacerbate air quality problems, in addition to wasting energy. In general, sealed duct systems specified with a leakage rate of less than 3% will have a superior life cycle cost analysis and reduce the likelihood of problems associated with leaky ductwork. Examples of excessive duct leakage leading to problems include:

- leakage of light troffer-type diffusers at the diffuser/light fixture interface when they are installed in a return plenum. Such leakage has been known to cause gross short-circuiting between supply and return, wasting much of the conditioned air. If the "room" thermostat is located in the return plenum, the room can be very uncomfortable while the temperature in the plenum is operating at the control setpoint.
- leakage of supply ductwork due to loose-fitting joints and connections or "blow outs" of improperly fabricated seams
- leakage of return ducts located in crawl spaces or below slabs, allowing soil gases and molds to enter the ductwork

which water vapor is added, is generally set at 70% to avoid condensation (with a potential for subsequent mold growth) in the ductwork. Adding water vapor to a building that was not designed for humidification can have a negative impact on the building structure and the occupants' health, if condensation occurs on cold surfaces or in wall or roof cavities.

Supply Fans

After passing through the coil section where heat is either added or extracted, air moves through the supply fan chamber and the distribution system. Air distribution systems commonly use ducts that are constructed to be relatively airtight. Elements of the building construction can also serve as part of the air distribution system (e.g., pressurized supply plenums or return air plenums located in the cavity space above the ceiling tiles and below the deck of the floor above). Proper coordination of fan selection and duct layout during the building design and construction phase and ongoing maintenance of mechanical components, filters, and controls are all necessary for effective air delivery.

Fan performance is expressed as the ability to move a given quantity of air (cubic feet per minute or cfm) at a given resistance or static pressure (measured in inches of water column). Airflow in ductwork is determined by the size of the duct opening, the resistance of the duct configuration, and the velocity of the air through the duct. The static pressure in a system is calculated using factors for duct length, speed of air movement and changes in the direction of air movement.

It is common to find some differences between the original design and the final installation, as ductwork must share limited space with structural members and other "hidden" elements of the building system (e.g., electrical conduit, plumbing pipes). Air distribution problems can occur, particularly at the end of duct runs, if departures from the original design increase the friction in the system to a point that approaches the limit of fan performance. Inappropriate use of long runs of flexible ducts with sharp bends also causes excessive friction. Poor system balancing (adjustment) is another common cause of air distribution problems.

Dampers are used as controls to restrict airflow. Damper positions may be relatively fixed (e.g., set manually during system testing and balancing) or may change in response to signals from the control system. Fire and smoke dampers can be triggered to respond to indicators such as high temperatures or signals from smoke detectors. If a damper is designed to modulate, it should be checked during inspections to see that it is at the proper setting. ASHRAE and the Associated Air Balance Council both provide guidance on proper intervals for testing and balancing.

Ducts

The same HVAC system that distributes conditioned air throughout a building air can distribute dust and other pollutants, including biological contaminants. Dirt or dust accumulation on any components of an air handling system — its cooling coils, plenums, ducts, and equipment housing — may lead to contamination of the air supply.

There is widespread agreement that building owners and managers should take great precautions to prevent dirt, high humidity, or moisture from entering the ductwork; there is less agreement at present about when measures to clean up are appropriate or how effective cleaning techniques are at making long-term improvements to the air supply or at reducing occupant complaints.

The presence of dust in ductwork does not necessarily indicate a current microbiological problem. A small amount of dust on duct surfaces is normal and to be expected. Special attention should be given to trying to find out if ducts are contaminated only where specific problems are present, such as: water damage or biological growth observed in ducts, debris in ducts that restricts airflow, or dust discharging from supply diffusers.

Problems with dust and other contamination in the ductwork are a function of filtration efficiency, regular HVAC system maintenance, the rate of airflow, and good housekeeping practices in the occupied space. Problems with biological pollutants can be prevented by minimizing dust and dirt build-up, promptly repairing leaks and water damage, preventing moisture accumulation in the components that are supposed to be dry, and cleaning the components such as the drip pans that collect and drain water.

In cases where sheet metal ductwork has become damaged or water-soaked, building owners will need to undertake clean-up or repair procedures. For example, in cases where the thermal liner or fiberboard has become water-soaked, building managers will need to replace the affected areas. These procedures should be scheduled and performed in a way that does not expose building occupants to increased levels of pollutants and should be carried out by experienced workers. Correcting theproblems that allowed the ductwork to become contaminated in the first place is important. Otherwise, the corrective action will only be temporary.

The porous surface of fibrous glass duct liner presents more surface area (which can trap dirt and subsequently collect water) than sheet metal ductwork. It is therefore particularly important to pay attention to the proper design, installation, filtration, humidity, and maintenance of ducts that contain porous materials. In addition, techniques developed for cleaning unlined metal ducts often are not suitable for use with fibrous glass thermal liner or fiberboard. Such ducts may require a special type of cleaning to maintain the integrity of the duct (i.e., no heavy brushing tools that might fray the inner lining) while removing dirt and debris.

More research on both the efficacy and the potential for unintended exposures to building occupants from various cleaning techniques is needed before firm guidance can be provided regarding duct cleaning.

Pay attention to worker safety when working with air handling systems including during duct cleaning. Any worker who may potentially breathe duct contaminants or biocides should wear suitable protective breathing apparatus. Workers who are doing the duct cleaning should be encouraged to also look for other types of problems, such as holes or gaps in the ducts that could allow contaminants to enter the ventilation airstream.

Building managers can obtain more information on the issue of HVAC contamination and cleaning from the professional standards developed by some trade associations (See *Guidelines of Care Developed by Professional and Trade Associations* in *Section 5* and refer to *Appendix G* for a list of organizations with expertise and materials on these issues.)

PRELIMINARY RECOMMENDATIONS ON DUCT CLEANING

1. Any duct cleaning should be scheduled during periods when the building is unoccupied to prevent exposure to chemicals and loosened particles.

The air handling unit should not be used during the cleaning or as an air movement device for the cleaning process. The National Air Duct Cleaning Association recommends that the system should be run to allow at least eight air changes in the occupied space when duct cleaning has been completed.

2. Negative air pressure that will draw pollutants to a vacuum collection system should be maintained at all times in the duct cleaning area to prevent migration of dust dirt, and contaminants into occupied areas.

Where possible, use vacuum equipment or fans during cleaning and sanitizing to make sure that cleaning vapors are exhausted to the outside and do not enter the occupied space.

3. If it is determined that the ductwork should be cleaned, careful attention must be given to protecting the ductwork.

When gaining access to sheet metal ducts for cleaning purposes, it is essential to seal the access hole properly in order to maintain the integrity of the HVAC system. Access doors are recommended if the system is to be cleaned periodically, and all access holes should be identified on the building's mechanical plans.

Particular attention is warranted when cutting fibrous glass ducts, and manufacturers' recommended procedures for sealing should be followed stringently. Use existing duct system openings where possible because it is difficult to repair the damage caused by cutting new access entries into the ductwork. Large, high volume vacuum equipment should only be used with extreme care because high negative pressure together with limited airflow can collapse ducts.

4. Duct cleaning performed with high velocity airflow (i.e., greater than 6,000 cfm) should include gentle, well-controlled brushing of duct surfaces or other methods to dislodge dust and other particles.

Duct cleaning that relies only on a high velocity airflow through the ducts is not likely to achieve satisfactory results because the flow rate at the duct surface remains too low to remove many particles.

5. Only HEPA filtered (high-efficiency particle arrestor) vacuuming equipment should be used if the vacuum collection unit is inside the occupied space.

Conventional vacuuming equipment may discharge extremely fine particulate matter back into the atmosphere, rather than collecting it. Duct cleaning equipment that draws the dust and dirt into a collection unit outside the building is also available. People should not be allowed to remain in the immediate vicinity of these collection units.

6. If biocides are to be used, then select only products registered by EPA for such use, use the products according to the manufacturer's directions, and pay careful attention to the method of application.

At present, EPA accepts claims and therefore registers antimicrobials for use only as sanitizers, not disinfectants or sterilizers in HVAC systems. (See *Appendix F* for definitions of antimicrobials.) There is some question about whether there are any application techniques that will deposit a sufficient amount of the biocide to kill bacteria, germs, or other biologicals that may be present. Materials such as deodorizers that temporarily eliminate odors caused by microorganisms provide only a fresh smell, and are not intended to provide real control of microbiological contaminants.

7. Use of sealants to cover interior ductwork surfaces is not recommended.

No application techniques have been demonstrated to provide a complete or long-term barrier to microbiological growth, nor have such materials been evaluated for their potential health effects on occupants. In addition, using sealants alters the surface burning characteristics of the duct material and may void the fire safety rating of the ductwork.

8. Careful cleaning and sanitizing of any parts of coils and drip pans can reduce microbiological pollutants.

Prior to using sanitizers, deodorizers, or any cleansing agents, carefully read the directions on the product label. Once cleaned, these components should be thoroughly rinsed and dried to prevent exposure of building occupants to the cleaning chemicals.

9. Water-damaged or contaminated porous materials in the ductwork or other air handling system components should be removed and replaced.

Even when such materials are thoroughly dried, there is no way to guarantee that all microbial growth has been eliminated.

10. After the duct system has been cleaned and restored to use, a preventive maintenance program will prevent the recurrence of problems.

Such a program should include particular attention to the use and maintenance of adequate filters, control of moisture in the HVAC system, and periodic inspection and cleaning of HVAC system components. (See discussion of *Preventive Maintenance* on page 36 in *Section 5*.)

Terminal Devices

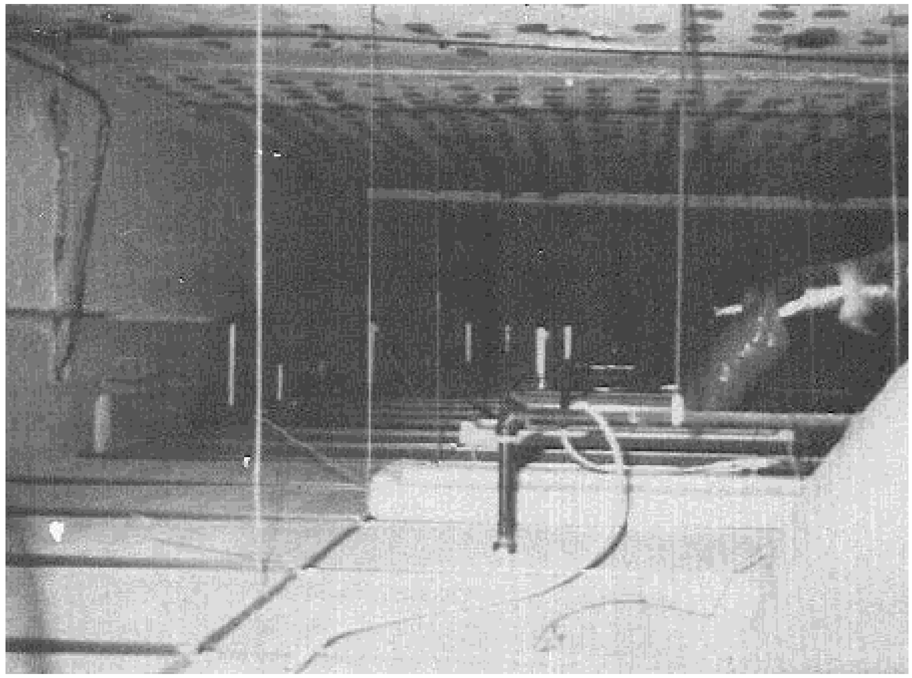
Thermal comfort and effective contaminant removal demand that air delivered into a conditioned space be properly distributed within that space. Terminal devices are the supply diffusers, return and exhaust grilles, and associated dampers and controls that are designed to distribute air within a space and collect it from that space. The number, design, and location (ceiling, wall, floor) of terminal devices are very important. They can cause a HVAC system with adequate capacity to produce unsatisfactory results, such as drafts, odor transport, stagnant areas, or short-circuiting.

Occupants who are uncomfortable because of distribution deficiencies (drafts, odor transport, stagnant air, or uneven temperatures) often try to compensate by adjusting or blocking the flow of air from supply outlets. Adjusting system flows without any knowledge of the proper design frequently disrupts the proper supply of air to adjacent areas. Distribution problems can also be produced if the arrangement of movable partitions, shelving, or other furnishings interferes with airflow. Such problems often occur if walls are moved or added without evaluating the expected impact on airflows.

Return Air Systems

In many modern buildings the above-ceiling space is utilized for the unducted passage of return air. This type of system approach often reduces initial HVAC system costs, but requires that the designer, maintenance personnel, and contractors obey strict guidelines related to life and safety codes (e.g., building codes) that must be followed for materials and devices that are located in the plenum. In addition, if a ceiling plenum is used for the collection of return air, openings into the ceiling plenum created by the removal of ceiling tiles will disrupt airflow patterns. It is particularly important to maintain the integrity of the ceiling and adjacent walls in areas that are designed to be exhausted, such as supply closets, bathrooms, and chemical storage areas.

After return air enters either a ducted return air grille or a ceiling plenum, it is returned to the air handlers. Some systems utilize return fans in addition to supply fans in order to properly control the distribution of air. When a supply and return fan are utilized, especially in a VAV system, their operation must be coordinated in order to prevent under- or overpressurization of the occupied space or overpressurization of the mixing plenum in the air handler.



Return air is frequently carried through non-ducted plenums. It is more difficult to control leakage of pollutants into or out of this type of return air system than a ducted system.

Exhausts, Exhaust Fans, and Pressure Relief

Most buildings are required by law (e.g., building or plumbing codes) to provide for exhaust of areas where contaminant sources are strong, such as toilet facilities, janitorial closets, cooking facilities, and parking garages. Other areas where exhaust is frequently recommended but may not be legally required include: reprographics areas, graphic arts facilities, beauty salons, smoking lounges, shops, and any area where contaminants are known to originate.

For successful confinement and exhaust of identifiable sources, the exhausted area must be maintained at a lower overall pressure than surrounding areas. Any area that is designed to be exhausted must also be isolated (disconnected) from the return air system so that contaminants are not transported to another area of the building.

In order to exhaust air from the building, make-up air from outdoors must be brought into the HVAC system to keep the building from being run under negative pressure. This make-up air is typically drawn in at the mixed air plenum as described earlier and distributed within the building. For exhaust systems to function properly, the make-up air must have a clear path to the area that is being exhausted.

It is useful to compare the total cfm of powered exhaust to the minimum quantity of mechanically-introduced outdoor air. To prevent operating the building under negative pressures (and limit the amount of unconditioned air brought into the building by infiltration), the amount of make-up air drawn in at the air handler should always be slighter greater than the total amount of relief air, exhaust air, and air exfiltrating through the building shell. Excess make-up air is generally relieved at an exhaust or relief outlet in the HVAC system, especially in air economizer systems. In addition to reducing the effects of unwanted infiltration, designing and operating a building at slightly positive or neutral pressures will reduce the rate of entry of soil gases when the systems are operating. For a building to actually operate at a slight positive pressure, it must be tightly constructed (e.g., specified at less than one-half air change per hour at 0.25 pascals). Otherwise unwanted exfiltration will prevent the building from ever achieving a neutral or slightly positive pressure.

Self-Contained Units

In some designs, small decentralized units are used to provide cooling or heating to interior or perimeter zones. With the exception of induction units, units of this type seldom supply outdoor air. They are typically considered a low priority maintenance item. If self-contained units are overlooked during maintenance, it is not unusual for them to become a significant source of contaminants, especially for the occupants located nearby.

Controls

HVAC systems can be controlled manually or automatically. Most systems are controlled by some combination of manual and automatic controls. The control system can be used to switch fans on and off, regulate the temperature of air within the conditioned space, or modulate airflow and pressures by controlling fan speed and damper settings. Most large buildings use automatic controls, and many have very complex and sophisticated systems. Regular maintenance and calibration are required to keep controls in good operating order. All programmable timers and switches should have “battery backup” to reset the controls in the event of a power failure.

Local controls such as room thermostats must be properly located in order to maintain thermal comfort. Problems can result from:

- thermostats located outside of the occupied space (e.g., in return plenum)
- poorly designed temperature control zones (e.g., single zones that combine areas with very different heating or cooling loads)
- thermostat locations subject to drafts or to radiant heat gain or loss (e.g., exposed to direct sunlight)

- thermostat locations affected by heat from nearby equipment

To test whether or not a thermostat is functioning properly, try setting it to an extreme temperature. This experiment will show whether or not the system is responding to the signal in the thermostat, and also provides information about how the HVAC system may perform under extreme conditions.

Boilers

Like any other part of the HVAC system, a boiler must be adequately maintained to operate properly. However, it is particularly important that combustion equipment operate properly to avoid hazardous conditions such as explosions or carbon monoxide leaks, as well as to provide good energy efficiency. Codes in most parts of the country require boiler operators to be properly trained and licensed.

Both ASME and ASHRAE have made recommendations of how much combustion air is needed for fuel burning appliances.

Elements of boiler operation that are particularly important to indoor air quality and thermal comfort include:

- Operation of the boiler and distribution loops at a high enough temperature to supply adequate heat in cold weather.
- Maintenance of gaskets and breeching to prevent carbon monoxide from escaping into the building.
- Maintenance of fuel lines to prevent any leaks that could emit odors into the building.
- Provision of adequate outdoor air for combustion.
- Design of the boiler combustion exhaust to prevent re-entrainment, (especially from short boiler stacks, or into multi-story buildings that were added after the boiler plant was installed).

It is important to determine periodically whether the HVAC controls are correctly calibrated. In addition, time clocks must be checked to see if they are properly set and running. Power failures frequently cause time clocks to be out of adjustment.

Modern office buildings tend to have much smaller capacity boilers than older buildings because of advances in energy efficiency. In some buildings, the primary heat source is waste heat recovered from the chiller (which operates year-round to cool the core of the building).

Cooling Towers

Maintenance of a cooling tower ensures proper operation and keeps the cooling tower from becoming a niche for breeding pathogenic bacteria, such as *Legionella* organisms. Cooling tower water quality must be properly monitored and chemical treatments used as necessary to minimize conditions that could support the growth of significant amounts of pathogens. Proper maintenance may also entail physical cleaning (by individuals using proper protection) to prevent sediment accumulation and installing drift eliminators.

FIGURE B-2: Selected Ventilation Recommendations

Application		Occupancy (people/1000 ft²)	Cfm/person	Cfm/ft²
Food and Beverage Service	Dining rooms	70	20	
	Cafeteria, fast food	100	20	
	Bars, cocktail lounges	100	30	
	Kitchen (cooking)	20	15	
Offices	Office space	7	20	
	Reception areas	60	15	
	Conference rooms	50	20	
Public Spaces	Smoking lounge	70	60	
	Elevators			1.00
Retail Stores, Sales Floors, Showroom Floors	Basement and street	30		0.30
	Upper floors	20		0.20
	Malls and arcades	20		0.20
	Smoking lounge	70	60	
Sports and Amusement	Spectator areas	150	15	
	Game rooms	70	25	
	Playing floors	30	20	
	Ballrooms and discos	100	25	
Theaters	Lobbies	150	20	
	Auditorium	150	15	
Education	Classroom	50	15	
	Music rooms	50	15	
	Libraries	20	15	
	Auditoriums	150	15	
Hotels, Motels, Resorts, Dormitories	Bedrooms			30 cfm/room
	Living rooms			30 cfm/room
	Lobbies	30	15	
	Conference rooms	50	20	
	Assembly rooms	120	15	

SOURCE: ASHRAE Standard 62-1989, Ventilation for Acceptable Air Quality

Water Chillers

Water chillers are frequently found in large building air conditioning systems because of the superior performance they offer. A water chiller must be maintained in proper working condition to perform its function of removing the heat from the building. Chilled water supply temperatures should operate in the range of 45°F or colder in order to provide proper moisture removal during humid weather. Piping should be insulated to prevent condensation.

Other than thermal comfort, IAQ concerns associated with water chillers involve potential release of the working fluids from the chiller system. The rupture disk (safety release) of the system should be piped to the outdoors, and refrigerant leaks should be located and repaired. Waste oils and spent refrigerant should be disposed of properly.

ASHRAE STANDARDS AND GUIDELINES

Standard 62-1989, "Ventilation for Acceptable Air Quality"

ASHRAE 62-1989 is intended to assist professionals in the proper design of ventilation systems for buildings. The standard presents two procedures for ventilation design, a "Ventilation Rate" procedure and an "Air Quality" procedure.

With the Ventilation Rate procedure, acceptable air quality is achieved by specifying a given quantity and quality of outdoor air based upon occupant density and space usage. Examples of the tables listing the prescriptive amounts of outdoor air for the Ventilation Rate procedure are presented at the end of this section.

The Air Quality procedure is a performance specification that allows acceptable air quality to be achieved within a space by controlling for known and specifiable contaminants. This procedure is seldom used because source strength is usually not known.

Whichever procedure is utilized in the design, the standard states that the design criteria and assumptions shall be documented and made available to those responsible for the operation and maintenance of the system.

Important features of ASHRAE 62-1989 include:

- a definition of acceptable air quality
- a discussion of ventilation effectiveness
- the recommendation of the use of source control through isolation and local exhaust of contaminants
- recommendations for the use of heat recovery ventilation
- a guideline for allowable carbon dioxide levels
- appendices listing suggested possible guidelines for common indoor pollutants

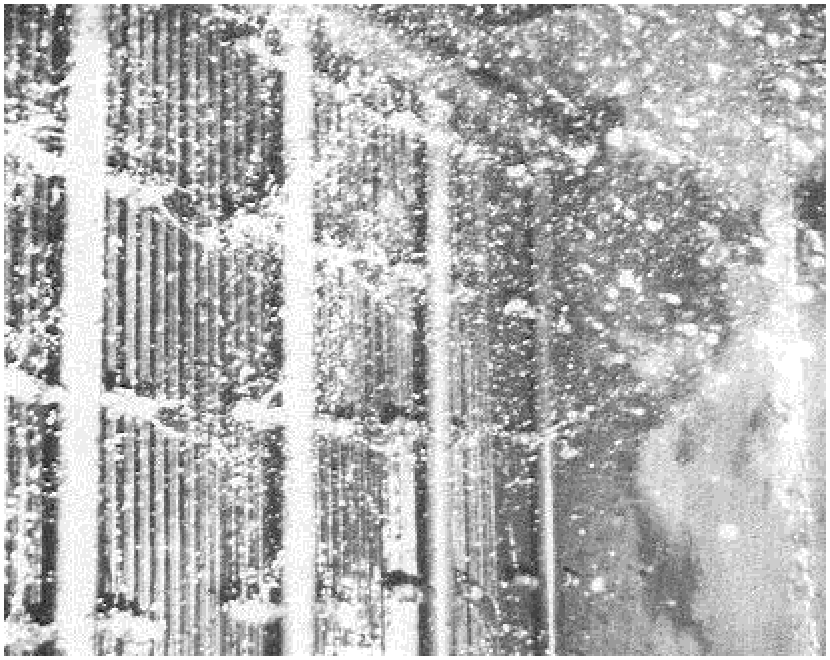
Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy"

ASHRAE 55-1981 covers several environmental parameters including: temperature, radiation, humidity, and air movement.

The standard specifies thermal environmental conditions for the comfort of healthy people in normal indoor environments for winter and summer conditions. It also attempts to introduce limits on the temperature variations within a space. In addition to specifications for temperature and humidity, guidelines are given for air movement, temperature cycling, temperature drift, vertical temperature difference, radiant asymmetry, and floor temperatures. Adjustment factors are described for various activity levels of the occupants, and different clothing levels.

Important features of this standard include:

- a definition of acceptable thermal comfort



This air washer is used to remove particles and water-soluble gaseous contaminants and may also control temperature and humidity in the airstream. Such systems are subject to severe bacterial contamination.

- a discussion of the additional environmental parameters that must be considered
- recommendations for summer and winter comfort zones for both temperature and relative humidity
- a guideline for making adjustment for activity levels
- guidelines for making measurements

It should be noted that space temperatures above 76°F but within the summer comfort envelope have nevertheless been associated with IAQ complaints in offices.

Note: As of summer 1991, a revised Standard 55 was nearly ready.

Standard 52-76, "Method of Testing Air-Cleaning Devices Used in General Ventilation for Removing Particulate Matter"

This standard is intended to assist professionals in the evaluation of air cleaning systems for particle removal. Two test methods are described: the weight arrestance test and the atmospheric dust spot test. The standard discusses differences in results from the weight arrestance test and the atmospheric dust spot test. The atmospheric dust spot test is the test used to determine the "efficiency " of an air cleaner. The values obtained with these two tests are not comparable. For example, a filter with a weight arrestance of 90% may have an efficiency by the atmospheric dust spot test below 40%.

The weight arrestance test is generally used to evaluate low efficiency filters designed to remove the largest and heaviest particles; these filters are commonly used in residential furnaces and/or air-conditioning systems or as upstream filters for other air cleaning devices. For the test, a standard synthetic dust is fed into the air cleaner and the proportion (by weight) of the dust trapped on the filter is determined. Because the particles in the standard dust are relatively large, the weight arrestance test is of limited value in assessing the removal of smaller, respirable-size particles from indoor air.

The atmospheric dust spot test is usually used to rate medium efficiency air cleaners. The removal rate is based on the cleaner's ability to reduce soiling of a clean paper target, an ability dependent on the cleaner removing very fine particles from the air. However, it should be noted that this test addresses the overall efficiency of removal of a complex mixture of dust, and that removal efficiencies for different size particles may vary widely. Recent studies by EPA, comparing ASHRAE ratings to filter efficiencies for particles by size, have shown that efficiencies for particles in the size range of 0.1 to 1 microgram are much lower than the ASHRAE rating.

Important features of this ASHRAE standard include:

- definitions of arrestance and efficiency
- establishment of a uniform comparative testing procedure for evaluating the performance of air cleaning devices used in ventilation systems

- establishment of a uniform reporting method for performance
- methods for evaluating resistance to airflow and dust-holding capacity

No comparable guidelines or standards are currently available for use in assessing the ability of air cleaners to remove gaseous pollutants or radon and its progeny.

Guideline 1-1989, "Guideline for the Commissioning of HVAC Systems"

This guideline is intended to assist professionals by providing procedures and methods for documenting and verifying the performance of HVAC systems so that they operate in conformity with the design intent. The guideline presents a format for documenting the occupancy requirements, design assumptions, and the design intent for the HVAC system. It provides a format for testing the system for acceptance by the owner. In addition, the guideline addresses adjustments of the system to meet actual occupancy needs within the capacity of the system when changes in building use are made and recommissioning is warranted.

Important features of this guideline include:

- definition of the commissioning process
- discussion of the process involved in a proper commissioning procedure
- sample specification and forms for logging information
- recommendation for the implementation of corrective measures as warranted
- guideline for operator training
- guidelines for periodic maintenance and recommissioning as needed